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A PROPOSED INTERNATIONAL TROPICAL REFERENCE ATMOSPHERE UP TO 80 km

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ABSTRACT

Motivated by the need in many aerospace applications for a meaningful reference atmosphere characteristic of the whole of the tropics in both the northern and southern hemispheres of the globe, a proposal is made here for such an atmosphere upto an altitude of 80 km. The proposal is based on balloonsonde, rocketsonde and grenade and falling sphere data, respectively, in the range of about 0-20, 20-50 and 50-80 km height. The final proposal consists of six linear segments in the temperature distribution, with temperature values in degrees Centigrade of 27, -9, -74,-5, -5, -74 and -74 at altitudes of 0, 9, 16, 46, 52, 75 and 80 km respectively. The sea level pressure is taken as 1010 mb, and abridged tables of quantities of interest in meteorological and aerospace applications are provided.

INTRODUCTION

With the large number of balloonsonde and meteorological rocket network (MRN) stations over the globe, and satellite soundings, it is now possible to characterise the atmosphere typical of a season, a month or even a day. However, a standard atmosphere representative of the mean annual conditions is still essential for many aerospace and remote sensing applications. An International Standard Atmosphere (ISA : see /1,2/) specified upto 32 km, and its proposed extension to higher altitudes such as in /3/, have been formulated for meeting these needs. These have been generally inspired by conditions in the temperate regions around mid-northern latitudes. However, conditions over the tropics can be substantially different from those specified in the International Standards; the authors have over the past many years sought to answer the question 'Is it possible to define a standard atmosphere which is close to the mean conditions over tropical India and elsewhere?'. During summer, tropical conditions prevail upto about 35^{o}N; during winter the change from extratropical to the tropical conditions occurs somewhere between 27^{o}N and 35^{o}N, probably around 30^{o}N /4/. Based on the available data it has indeed turned out to be possible to formulate a suitable Indian Standard Tropical Atmosphere (ISTA), valid upto 80 km and about 30^{o}N in latitude /5,6,7,8/.

The following facts suggest that, with minor modifications, it should be possible to provide an International Tropical Reference Atmosphere (ITRA) representative of the mean annual conditions and suitable for the whole of the tropical region in both the northern and southern hemispheres. First a study of the balloonsonde results (00 GMT) upto 20 km for stations at other longitudinal locations in North America (see Table 1) shows that

conditions are not very different from those prevailing over India. Secondly, even at altitudes upto 80 km, Cole and Kantor /9/ show that longitudinal variations during summer are small at all latitudes and at all altitudes above 20 km; during winter longitudinal variations become important only in arctic and sub-arctic latitudes.

We have considered the data at various longitudes in the tropics in formulating the present proposal. None of the reference atmospheres formulated earlier for the tropics (e.g. /9 to 16/) covers the latitude and altitude range of the present proposal.

Finally, it is well known from /9/ that latitudinal variations are weaker in the tropics than in the temperate regions; hence it should be possible to formulate a meaningful global reference for the tropics. The subsequent section discusses the nature, accuracy and consistency of the data available for the present study.

DATA BASE FOR PRESENT WORK

Temperature Data

The present standard is developed in three parts, namely
(i) in the troposphere and lower stratosphere, using balloonsonde data,
(ii) in the upper stratosphere, utilising rocketsonde data, and
(iii) in the mesosphere, considering grenade and falling sphere data.

Table 1 also shows the details of the station, type of instrumentation used, duration of available data and reference from which the data have been obtained.

Remarks on the Quality and Consistency of Data

Table 1 shows the pre- and post- 1970 IMD data when it switched from chronometric and fantype recorders to the audio-modulated type in the radiosonde. The effect of this, as noticed by us in /5/ and by Van de Boogard in /17/, is that during July over Nagpur, e.g., the later temperature values are lower by about 5°C at 100 mb level. However, considering the variation of temperature over the range of stations in the Indian subcontinent and during a year, such discrepancies lower the grand mean among stations only by about 2-3°C, and thus would not strongly alter the present proposal. Table 1 further shows data for some typical stations in India and in the American region; these are broadly consistent and confirm that a proposal (upto 20 km), valid for the whole tropical region over the world, should be feasible.

For the 20 to 50 km range, commencing from the late sixties when several MRN stations were set up, extensive (generally once-weekly) rocketsonde data are available as mentioned earlier. The wiretype thermistor probe used on the Russian M-100 rocketsonde and the bead type thermistor probe on American rocketsondes are fairly consistent upto 50 km. However these probes have shown differences of as much as 15°C around 70 km during the many intercomparison experiments carried out at Wallops Island and reported in /18,19,20/. It is possible that these differences are due to the free molecular conditions prevailing at altitudes beyond about 50 km, but no universally accepted resolution of these differences is yet available. Thus rocketsonde data available at many stations over the globe have been used only in the range from about 20 to 50 km.

For the higher altitude range of 50 to 80 km we have used mainly the falling sphere and grenade data (/29/,/32/ and the references to previous work cited there), which are consistent among

TABLE 1 Station Temperature Data for the Proposed ITRA

STATION	LAT	LONG	PERIOD & DATA	ALT IN KM -----> STATION	1.5	3.1	5.8	9.7	12.4	14.2	16.6	20.7	REF NO
TRIVANDRUM	9 N	77 E	50-71 B	300	291	283	268	242	221	208	198	211	/26/
NAGPUR	21 N	79 E	50-71 B	300	294	283	267	242	222	210	199	210	/26/
NEW DELHI	29 N	77 E	50-71 B	297	292	281	264	240	223	214	204	214	/26/
SRINAGAR	34 N	75 E	50-71 B	286		278	260	236	222	217	211		/26/
TRIVANDRUM	9 N	77 E	73-78 B	299	290	282	267	242	220	205	194	210	/27/
NAGPUR	21 N	79 E	73-78 B	300	294	283	267	243	222	209	197	209	/27/
NEW DELHI	29 N	77 E	73-78 B	298	291	280	264	239	221	211	200	211	/27/
KWAJALEIN	9 N	168 W	69-76 B	304	293	285	269	243	221	207	195	208	/15/
BROWNSVILLE	26 N	97 W	71-80 B	293	289	281	264	237	217	207	200	211	/27/
AP.CHICOLA	30 N	85 W	71-80 B	290	286	278	263	236	217	209	204	212	/27/
			ALT IN KM ----->	25	30	35	40	45	50	55	60	65	
ASCENSION	8 S	14 W	69-76 T	221	232	243	258	269	270	264	254	238	/21/
THUMBA (a)	9 N	168 E	70-76 T	221	232	244	258	264	262	248	218	209	/28/
KWAJALEIN	9 N	77 E	69-76 T	220	230	240	255	266	270	261	246	230	/15/
FT.SHERMAN	9 N	80 W	69-76 T	222	231	243	257	268	271	267	259		/21/
ANTIGUA	17 N	62 W	69-76 T	222	232	242	256	267	269	264	253	236	/21/
BARK.SANDS	22 N	160 W	69-76 T	221	231	241	254	266	268	263	254	234	/21/
CP.KENNEDY	28 N	80 W	69-76 T	222	231	242	255	267	268	263	255	239	/21/
WHT. SANDS	32 N	106 W	69-76 T	221	229	240	254	266	268	262	254	246	/21/
			ALT IN KM ----->	40	45	50	55	60	65	70	75	80	
ASCENSION	8 S	14 W	60-71 G	(251	(261	(263	(257	(242	(222	(202	(191	(188	/29/
and NATAL(b)	6 S	35 W	60-71	-259)	-271)	-271)	-263)	-252)	-234)	-220)	-211)	-206)	
THUMBA (c)	9 N	77 E	71-77 T	259	267	269	256	242	227	213	205	193	/28/
KWAJALEIN	9 N	168 W	56-78 *	255	266	270	261	246	230	213	200	196	/15/
WOOMERA (d)	31 S	137 E	57-63 S	254	267	267	259	249	232	218	204	191	/30/
WOOMERA (e)	31 S	137 E	57-63 G	(239 -263)		(258 -281)		(235 -255)		(205 -235)		(185 -208)	/31/

\+ B = Balloon, G = Grenade, S = Sphere, T = Thermistor, * = T & S
(a) Without adjustment of Ref/18/ ;
(b) Mean +/- Standard deviation ;
(c) With adjustment of Ref/18/ ;
(d) Approximate values from Fig.3 of Ref/30/ ;
(e) Approximate range from Fig.3 of Ref/31/.

themselves and possess an accuracy of about 2-3°C as given in /13/. Smith et al. /29/ report pitot tube data as well, but these lead to temperatures which are about 5°C higher on an average from the grenade data; as the reason for this is not clear, we have not considered the pitot data. Data in this altitude range are not as extensive as one would wish, but are perhaps barely adequate to propose a reasonable standard for describing the mean conditions.

Beyond an altitude of 80 km molecular dissociation commences, and above 100 km molecular diffusion predominates, and so air can no longer be treated as a perfect gas. It is then necessary to specify at each level the (varying) concentration of different species constituting air. Hence an altitude of 80 km is a natural limit to the present kind of standard.

PROPOSED INTERNATIONAL TROPICAL REFERENCE ATMOSPHERE (ITRA) UP TO 80 KM

The philosophy adopted by the authors in proposing the reference has been that it should

(a) be reasonably close to mean conditions,

(b) within the range of variation inherent in the atmosphere over space and time and the uncertainty in the data, be as simple as possible,

(c) adopt, where no physical principles are violated, as many of the parameters in the ISA as possible, and

(d) be dynamically consistent.

Temperature Distribution with Altitude

Table 1 shows the station mean data, and Figure 1 the grand mean among all stations excluding the relatively high latitude stations at Srinagar and Woomera, for the temperature between sea level and about 90 km. In the mesospheric region the grand mean is weighted towards low latitude stations. But Wallops Islands data in /3/ indicate that the latitudinal variation (at least between 50 and 70 km) is weak. Usually straight lines best fitting the data are used to describe the temperature distribution with altitude. This is because closed-form integration of the governing equation to obtain other atmospheric properties is then possible.

As the data indicate, the proposed standard has a sea level temperature of 27°C, and a lapse rate of 6°C/km upto 6 km and 6.5°C/km (as in ISA) from 6 to 16 km, the tropopause height. This tropopause height, and the corresponding temperature of -74°C, seem quite appropriate as argued in our previous work, and are also consistent with the various monthly reference atmospheres at the equator, 15°N and 30°N proposed by Cole and Kantor /9/. Further, in the stratosphere, a single lapse rate of -2.3°C/km all the way upto a stratopause height of 46 km, with a temperature of -5°C, fits the data very well. Though this temperature is somewhat higher than indicated by the Thumba value /28/, we consider it appropriate because of the fact that the stratopause temperature decreases with increasing latitudes /9/. The available data in the mesosphere indicate that it would be worthwhile to extend the constant temperature stratopause upto 52 km. It should be noted that in the mesosphere inversions occur during some months and there are well known double mesopauses with different temperature values as well /21/. But considering the totality of the data, and the average value that can be assigned at different levels over many stations, it is seen that once again a constant lapse rate of 3°C/km from 52 km to 75 km,

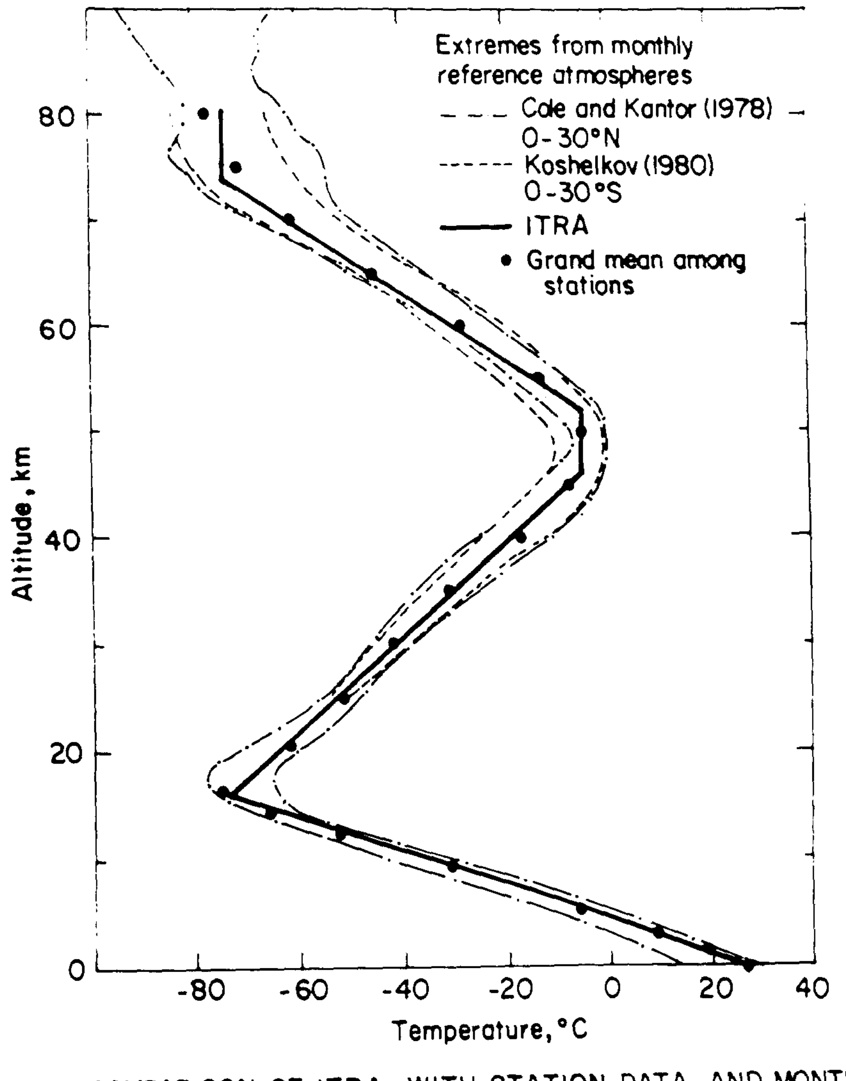

FIG. I COMPARISON OF ITRA WITH STATION DATA AND MONTHLY REFERENCE ATMOSPHERES

leading to a temperature of -74°C (as at tropopause) by the beginning of the mesopause, is justified. The constant temperature mesopause extends upto 80 km, which is the limit of the present proposal.

The present tropical reference is within the range of the extremes based on the temperature values in the monthly reference atmospheres for the tropical regions proposed for the northern and southern hemispheres in /9/ and /16/ respectively; these are also shown in Figure 1. We further expect that the present proposal should certainly be valid as an annual average between 26°N and 26°S in latitude; however comparison with data at Srinagar (34°N) and White Sands (32°N) shows that during summer the conditions are quite close to the present proposal, and that even the annual means do not show strong deviations at these slightly higher latitudes. (Conditions during winter can however be appreciably different.)

Mean Sea level Pressure

Seasonal pressure variations, like those of the temperature, increase with latitude, the mean pressure being lower during summer and higher during winter. Consideration of the mean annual station level pressures at Indian stations, extrapolated to sea level conditions, gives a value of about 1010 mb based on hourly data /22/. In ISTA, we had used a lower value of 1005 mb, consistent with the somewhat higher sea level temperature value of 30°C chosen to provide a slight bias towards the hot day that was considered desirable for aeronautical work. The more accurate sea level temperature of 27°C now proposed goes with the higher value of 1010 mb for sea level pressure. Cole and Kantor /9/, using mostly data from Western longitudes, also obtain a mean pressure close to this value. Only towards 30°N and beyond does the mean pressure increase appreciably. A further study of the Southern and Northern hemisphere data for the years 1951 to 1960 from /23/ for nearly 200 tropical stations shows that the above annual value is appropriate. It may be noted that the variation in annual mean pressure at a given station is of the order of a few mb. Different countries adopt slightly different methods for reducing the station level pressure to sea level conditions /24/, but these lead to differences even smaller than 1 mb and thus do not affect our proposal.

Acceleration due to Gravity

For this we suggest a value corresponding to the Tropic of Cancer, which from Lambert's formula given in /25/ gives 9.78852 ms^{-2} (truncated to five decimal places).

ATMOSPHERIC TABLES

Table 2 below specifies the temperature distribution for the present International Tropical Reference Atmosphere, as also the other constants adopted for generating the atmospheric table.

TABLE 2 Defining Parameters and Constants for the Proposed ITRA

Alt (km)	0	6	16	46	52	75	80
Temp (°C)	27(6.0)	-9(6.5)	-74(-2.3)	-5(0.0)	-5(3.0)	-74(0.0)	-74

The bracketed quantities denote lapse rate in °C/km.
Sea level Pressure = 1010 mb ;
Acceleration due to gravity = 9.78852 ms^{-2}.

The molecular weight, the ratio of the specific heats of air, the gas constant, and the other constants for the transport properties, are assumed to be the same as in /3/.

TABLE 3 Atmospheric Properties of ITRA (SI Units)

PRESSURE (mb)	GEOPT ALT (m)	NUMBER DENSITY (m^{-3})	MEAN PARTICLE SPEED (m/s)	MEAN COLLSN FREQ (s^{-1})	MEAN FREE PATH (m)	DYNAMIC VISCTY kg/(m.s)	KINMATIC VISCTY (m^2/s)	THERMAL CONDVTY W/(m.K)
1.010 3	00	2.437 25	4.684 2	6.757 9	6.932-8	1.847-5	1.575-5	2.626-2
8.500 2	1500	2.114 25	4.614 2	5.774 9	7.990-8	1.804-5	1.774-5	2.556-2
7.000 2	3130	1.802 25	4.535 2	4.837 9	9.377-8	1.757-5	2.027-5	2.479-2
5.000 2	5820	1.365 25	4.403 2	3.559 9	1.237-7	1.677-5	2.553-5	2.350-2
3.000 2	9610	9.028 24	4.195 2	2.241 9	1.871-7	1.551-5	3.571-5	2.151-2
2.000 2	12360	6.502 24	4.036 2	1.553 9	2.598-7	1.455-5	4.653-5	2.002-2
1.500 2	14190	5.151 24	3.926 2	1.197 9	3.280-7	1.390-5	5.609-5	1.902-2
1.000 2	16610	3.611 24	3.829 2	8.185 8	4.678-7	1.332-5	7.666-5	1.814-2
5.000 1	20790	1.723 24	3.919 2	3.998 8	9.804-7	1.386-5	1.672-4	1.896-2
3.000 1	23990	9.989 23	3.988 2	2.358 8	1.691-6	1.426-5	2.969-4	1.958-2
2.000 1	26610	6.480 23	4.042 2	1.550 8	2.607-6	1.459-5	4.682-4	2.008-2
1.000 1	31260	3.092 23	4.138 2	7.573 7	5.464-6	1.517-5	1.020-3	2.098-2
5.000 0	36140	1.475 23	4.236 2	3.699 7	1.145-5	1.576-5	2.221-3	2.190-2
2.000 0	42940	5.548 22	4.369 2	1.435 7	3.045-5	1.656-5	6.206-3	2.317-2
1.000 0	48350	2.701 22	4.427 2	7.078 6	6.255-5	1.691-5	1.302-2	2.374-2
5.000-1	53780	1.378 22	4.383 2	3.575 6	1.226-4	1.664-5	2.511-2	2.331-2
2.000-1	60570	5.975 21	4.210 2	1.489 6	2.827-4	1.560-5	5.428-2	2.165-2
1.000-1	65350	3.175 21	4.083 2	7.675 5	5.320-4	1.484-5	9.715-2	2.046-2
5.000-2	69850	1.688 21	3.961 2	3.956 5	1.001-3	1.410-5	1.737-1	1.933-2
2.000-2	75390	7.274 20	3.815 2	1.643 5	2.323-3	1.324-5	3.784-1	1.802-2
1.000-2	79440	3.637 20	3.815 2	8.214 4	4.645-3	1.324-5	7.567-1	1.802-2

TABLE 4 : ATMOSPHERIC PROPERTIES OF ITRA (LARGELY SI UNITS)

GEOPT ALT (m)	PRES ALT (m)	TEMP DEGREE (K)	PRESSURE (mb)	PRESSURE RATIO	DENSITY (kg/m^3)	DENSITY RATIO	SONIC VELCTY (m/s)	UNIT REY NUMBER (s/m^2)
-2000	-1890	312.15	1.262 3	1.250 0	1.408 0	1.202 0	354.18	7.402 0
00	30	300.15	1.010 3	1.000 0	1.172 0	1.000 0	347.31	6.348 0
2000	1940	288.15	8.010 2	7.930-1	9.684-1	8.261-1	340.29	5.412 0
4000	3840	276.15	6.290 2	6.227-1	7.934-1	6.769-1	333.13	4.584 0
6000	5740	264.15	4.886 2	4.838-1	6.444-1	5.497-1	325.81	3.856 0
8000	7640	251.15	3.750 2	3.712-1	5.201-1	4.437-1	317.70	3.240 0
10000	9540	238.15	2.837 2	2.809-1	4.150-1	3.540-1	309.36	2.700 0
12000	11430	225.15	2.113 2	2.093-1	3.270-1	2.790-1	300.80	2.228 0
14000	13410	212.15	1.547 2	1.532-1	2.540-1	2.167-1	291.99	1.819 0
16000	15520	199.15	1.110 2	1.099-1	1.942-1	1.657-1	282.90	1.467 0
18000	17660	203.75	7.914 1	7.836-2	1.353-1	1.154-1	286.15	1.002 0
20000	19760	208.35	5.684 1	5.628-2	9.503-2	8.107-2	289.36	6.908-1
22000	21820	212.95	4.112 1	4.071-2	6.726-2	5.738-2	292.54	4.800-1
24000	23860	217.55	2.995 1	2.965-2	4.796-2	4.091-2	295.68	3.362-1
26000	25870	222.15	2.196 1	2.175-2	3.444-2	2.938-2	298.79	2.373-1
28000	27860	226.75	1.621 1	1.605-2	2.490-2	2.124-2	301.87	1.686-1
30000	29820	231.35	1.203 1	1.192-2	1.812-2	1.546-2	304.92	1.207-1
32000	31770	235.95	8.988 0	8.899-3	1.327-2	1.132-2	307.93	8.697-2
34000	33700	240.55	6.750 0	6.683-3	9.776-3	8.339-3	310.92	6.307-2
36000	35640	245.15	5.097 0	5.047-3	7.244-3	6.179-3	313.88	4.602-2
38000	37590	249.75	3.869 0	3.831-3	5.397-3	4.604-3	316.81	3.378-2
40000	39550	254.35	2.952 0	2.923-3	4.043-3	3.449-3	319.71	2.494-2
42000	41510	258.95	2.263 0	2.241-3	3.045-3	2.597-3	322.59	1.851-2
44000	43480	263.55	1.743 0	1.726-3	2.304-3	1.966-3	325.44	1.381-2
46000	45460	268.15	1.349 0	1.335-3	1.752-3	1.495-3	328.27	1.036-2
48000	47470	268.15	1.046 0	1.035-3	1.359-3	1.159-3	328.27	8.034-3
50000	49480	268.15	8.110-1	8.030-4	1.054-3	8.988-4	328.27	6.230-3
52000	51490	268.15	6.289-1	6.226-4	8.170-4	6.969-4	328.27	4.831-3
54000	53500	262.15	4.862-1	4.814-4	6.462-4	5.512-4	324.58	3.890-3
56000	55510	256.15	3.737-1	3.700-4	5.083-4	4.336-4	320.84	3.117-3
58000	57520	250.15	2.855-1	2.826-4	3.975-4	3.391-4	317.06	2.485-3
60000	59540	244.15	2.166-1	2.145-4	3.091-4	2.637-4	313.24	1.970-3
62000	61560	238.15	1.633-1	1.616-4	2.388-4	2.037-4	309.36	1.553-3
64000	63580	232.15	1.222-1	1.209-4	1.833-4	1.564-4	305.44	1.218-3
66000	65610	226.15	9.071-2	8.981-5	1.397-4	1.192-4	301.47	9.484-4
68000	67640	220.15	6.682-2	6.616-5	1.057-4	9.020-5	297.44	7.339-4
70000	69670	214.15	4.881-2	4.832-5	7.940-5	6.773-5	293.36	5.640-4
72000	71710	208.15	3.533-2	3.499-5	5.914-5	5.045-5	289.22	4.302-4
74000	73760	202.15	2.534-2	2.509-5	4.367-5	3.725-5	285.02	3.257-4
76000	75830	199.15	1.802-2	1.784-5	3.151-5	2.688-5	282.90	2.381-4
78000	77870	199.15	1.279-2	1.266-5	2.238-5	1.909-5	282.90	1.690-4
80000	79860	199.15	9.082-3	8.992-6	1.589-5	1.355-5	282.90	1.200-4

Tables 3 and 4 give the atmospheric properties useful in meteorological and aerospace applications. More detailed atmospheric tables and the computer code used for generating them are available on request from the authors.

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